TITLE OF THE INVENTION

METHOD AND APPARATUS FOR TRANSMITTING

HIGH-FREQUENCY SIGNALS IN OPTICAL COMMUNICATION SYSTEM

5   BACKGROUND OF THE INVENTION

Field of the Invention:

This invention relates to a method and apparatus for transmitting high-frequency signals in an optical communication system. Especially, the invention relates to a method and apparatus

10   for transmitting high-frequency subcarrier signals in an optical communication system that utilizes the optical heterodyne detection technique with a dual-mode local light source and is hard to be affected by phase noise of light sources.

15   Description of the Prior Art:

It has been theoretically proven that receiving sensitivity of coherent optical communication systems with strong local light is superior to that of conventional intensity-modulation/direct-detection systems. Therefore, the coherent optical communication

20   systems had been looked to as a next-generation optical communication system. However, optical amplifiers have been developed in recent years in order to improve the receiving sensitivity of existing systems, and this, together with the difficulty of controlling the local light source to reduce phase-noise effect from light sources

25   in coherent optical communication systems, means that coherent optical communication systems are not yet practical.

In conventional optical fiber systems transmitting high-frequency signals, an optical carrier from a light source is modulated, amplified if necessary, and transmitted to a remote site.

30   The optical signal is again amplified if the transmission attenuates

the signal power, and then demodulated. Figure 2 shows an example of such a configuration, which comprises a single-mode light source 101, a high-frequency signal 102, an optical modulator 103, an optical amplifier 104, an optical transmission line 105, another
5   optical amplifier 106, a compensator 107 that compensates for the optical-fiber dispersion effect, a photo-detector 108, and a demodulator 109 that demodulates the high-frequency signal detected by the photo-detector 108.

An optical carrier emitted by the light source 101 is modulated
10 with the optical modulator 103 by the high-frequency signal 102 with payload data. The optical amplifier 104 amplifies the modulated optical signal up to the required power for transmission, and then the amplified optical signal is transmitted along the optical transmission line 105. To compensate for transmission loss and
15 insertion loss due to the optical-fiber dispersion compensator 107, the optical amplifier 106 in front of the optical-fiber dispersion compensator 107 amplifies again the optical signal. To eliminate any effect from optical-fiber dispersion arising in the following photo-detection stage, the optical-fiber dispersion compensator 107
20 performs compensation on a wavelength-by-wavelength basis. The received optical signal is directly detected by the photo-detector 108, and then the photo-detected signal is demodulated with the demodulator 109 to recover the payload data.

In the conventional system, in order to extend the transmission
25 distance, it has been necessary to use multiple optical amplifiers to increase the received signal power to a level large enough to ensure the desired communication quality. However, light that is spontaneously emitted from an optical amplifier is amplified with the following optical amplifiers, causing accumulation of
30 spontaneously emitted light. This spontaneously emitted light

cannot be removed any longer in the case of analog optical communication systems. Once it is detected by the photo-detector, the spontaneously emitted light forms noise that corrupts the desired signal quality. The noise is well-known as an amplified spontaneous

5 emission (ASE) noise. Moreover, in the conventional system additional optical-fiber dispersion compensators must be added to nullify the effect of the optical-fiber dispersion. However, since the dispersion effect strongly depends on both the wavelength and the transmission distance involved, the optical-fiber dispersion

10 compensators must have been individually adjusted, making the configuration of the optical communication systems more complex.

In view of the foregoing, an object of the present invention is to provide an optical communication system not only that does not need to use any optical amplifiers that give rise to ASE noise, but

15 also in which phase noise of light sources is removed in principle.

Another object of the invention is to provide a system that is not affected by optical-fiber dispersion effect, thereby eliminating the use of additional optical-fiber dispersion compensators that are required in the conventional system.

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SUMMARY OF THE INVENTION

The optical communication system according to this invention transmits an optical carrier that is modulated by a high-frequency signal with payload data. On the receiving side, the optical signal

25 is detected by the optical heterodyne detection technique with a dual-mode local light. The optical carrier component and a desired optical sideband component are extracted from photo-detected signals in the first intermediate-frequency-band, and the two extracted signals are cross-multiplied, converting to a desired signal in the

30 second intermediate-frequency-band. The same amount of the

inherent phase noise of both the light source generating the optical carrier and the dual-mode local light source generating the local light, which is included each in the extracted signal from the first intermediate-frequency-band signals, is differentially removed 5 when the cross-multiplying is performed.

In accordance with the first aspect of the invention, the above objects are attained by a method for transmitting high-frequency signals in an optical communication system, comprising the steps of combining an optical signal, a first optical local component from 10 a local light source, and a second optical local component from the local light source having a predetermined frequency differential from the first optical local component, selecting a first high-frequency signal which consists of two predetermined electrical components from plural electrical components obtained by an optical 15 frequency mixing process, and mixing the two selected electrical components included in the first high-frequency signal.

The second aspect of the method of the invention relates to the use of intermediate-frequency-band signals, and comprises the steps of transmitting an optical signal that includes an optical 20 carrier component and an optical sideband component obtained by modulation with a high-frequency signal whose frequency is predetermined, combining the optical signal, a first optical local component from a local light source, and a second optical local component from the local light source having a predetermined 25 frequency differential from the first optical local component, selecting a first high-frequency signal which consists of two predetermined electrical components from plural photo-detected electrical components obtained by an optical frequency mixing process, and selecting a second high-frequency signal whose 30 frequency is lower by an amount of predetermined frequency

differential than a carrier frequency of the first high-frequency signal obtained by the optical frequency mixing process.

The third aspect relates to demodulation by optical frequency mixing, and comprises the steps of transmitting an optical signal
5　that includes an optical carrier component and an optical sideband component obtained by modulation with a high-frequency signal whose frequency is predetermined, extracting an original high-frequency signal from the transmitted optical signal, combining the optical signal, a first optical local component from a local light source
10　and a second optical local component from the local light source having a predetermined frequency differential from the first optical local component, making a carrier frequency of the extracted original high-frequency signal coincide with the predetermined frequency differential, and selecting two predetermined electrical components
15　from plural electrical components obtained by an optical frequency mixing process.

In accordance with a fourth aspect, which relates specifically to the use of optical filtering, the method of the invention comprises the steps of transmitting an optical signal that includes an optical
20　carrier component and an optical sideband component obtained by modulation with a high-frequency signal whose frequency is predetermined, combining the optical signal, a first optical local component from a local light source and a second optical local component from the local light source having a predetermined
25　frequency differential from the first optical local component, selecting, as a first optical signal, lights containing the optical sideband component included in the optical signal and the first optical local component from the local light source, selecting, as a second optical signal, lights containing the optical carrier
30　component included in the optical signal and the second optical local

component from the local light source, and selecting a signal with a relatively low frequency after mixing the first and second optical signals.

In accordance with a fifth aspect of the invention, the above
5 objects are attained by an apparatus for transmitting high-frequency signals in an optical communication system, the apparatus comprising means for combining an optical signal, a first optical local component from a local light source and a second optical local component from the local light source having a predetermined
10 frequency differential from the first optical local component, means for selecting a first high-frequency signal which consists of two predetermined electrical components from plural electrical components obtained by an optical frequency mixing process, and means for mixing the two selected electrical components included in the
15 first high-frequency signal.

In a sixth aspect relating specifically to the use of intermediate-frequency-band signals, the apparatus comprises means for transmitting an optical signal that includes an optical carrier component and an optical sideband component obtained by modulation
20 with a high-frequency signal whose frequency is predetermined, means for combining the optical signal, a first optical local component from a local light source and a second optical local component from the local light source having a predetermined frequency differential from the first optical local component, means for selecting a first
25 high-frequency signal which consists of two predetermined electrical components from plural electrical components obtained by an optical frequency mixing process, and means for selecting a second high-frequency signal whose frequency is lower by an amount of predetermined frequency differential than a carrier frequency of the
30 first high-frequency signal obtained by the optical frequency mixing

process.

In a seventh aspect, the apparatus comprises means for transmitting an optical signal that includes an optical carrier component and an optical sideband component obtained by modulation
5 with a high-frequency signal whose frequency is predetermined, means for extracting the original high-frequency signal from the transmitted optical signal, means for combining the optical signal, a first optical local component from a local light source and a second optical local component from the local light source having a
10 predetermined frequency differential from the first optical local component, means for making a carrier frequency of the extracted original high-frequency signal coincide with the predetermined frequency differential, and means for selecting two predetermined electrical components from plural electrical components obtained by
15 an optical frequency mixing process.

In an eighth aspect, relating to the use of an optical filter, the apparatus comprises means for transmitting an optical signal that includes an optical carrier component and an optical sideband component obtained by modulation with a high-frequency signal whose
20 frequency is predetermined, means for combining the optical signal, a first optical local component from a local light source and a second optical local component from the local light source having a predetermined frequency differential from the first optical local component, means for selecting, as a first optical signal, lights
25 containing the optical sideband component included in the optical signal and the first optical local component from the local light source, means for selecting, as a second optical signal, lights containing the optical carrier component included in the optical signal and the second optical local component from the local light
30 source, and means for selecting a signal with a relatively low

frequency after mixing the first and second optical signals.

In a ninth aspect, the arrangement used for generating optical signals that are to be transmitted comprises means for generating an optical carrier component with a single-mode light source that

5 produces a single-mode optical carrier, and means for generating an optical sideband component obtained by modulating the optical carrier component by a high-frequency signal by means of optical modulation.

In a tenth aspect, which relates to the means of optical frequency mixing, the apparatus uses the combining means which has

10 a configuration that projects plural light beams onto a photo-detector to be combined and extracts at least part of combined optical signal as electrical signals.

In an eleventh aspect, in order to eliminate the intensity fluctuations of light emitted from light sources, the photo-detector

15 is configured as a balanced receiver.

In accordance with a twelfth aspect relating to the use of a dual-mode local light source, in the means for generating the first optical local component and the second optical local component having a predetermined frequency differential from the first optical local

20 component, two desired continuous waves are obtained from an optical spectrum emitted from a pulsed light source; from an optical spectrum emitted from a pulsed light source using optical injection locking; by utilizing a light source that emits two adjacent lightwaves; and by selectively producing two lightwaves by modulating light from a

25 single-mode light source.

The above and other objects and features of the invention will become apparent from the following description made with reference to the drawings.

BRIEF EXPLANATION OF THE DRAWINGS

Figure 1 is a schematic diagram of an optical communication system of a high-frequency signal, according to the present invention.

5   Figure 2 is a schematic diagram of an example of a conventional radio-on-fiber system.

Figure 3 is a diagram showing an example of optical spectra before photo-detection in the invented system.

Figure 4 is a diagram showing an example of spectra of electrical
10   signals in the first intermediate-frequency-band.

Figure 5 shows the measured spectra of a received optical signal and a dual-mode local light.

Figure 6 shows the measured spectra of electrical signals in the first intermediate-frequency-band.

15   Figure 7 shows the measured spectra of electrical signals in the second intermediate-frequency-band.

Figure 8 shows the measured bit error rate.

Figure 9 is a schematic diagram of the second embodiment of the present invention.

20   Figure 10 is a schematic diagram of the third embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In the following, embodiments of the present invention are
25   explained with reference to examples shown in the drawings. Throughout the embodiments illustrated in the drawings, identical reference symbols indicate parts having identical or similar functions or configurations. It is to be understood that the invention is not limited to the specific examples described
30   hereinafter.

An optical communication system according to this invention
transmits an optical carrier modulated by a high-frequency signal
with payload data. This transmission is done without the signal
being amplified. On the receiving side, a dual-mode local light
5   source is utilized to implement signal detection by optical
heterodyne detection. The optical carrier component and a desired
optical sideband component are extracted from photo-detected signals
in the first intermediate-frequency-band. The two extracted
signals are cross-multiplied, converting the high-frequency signal
10   in the first intermediate-frequency-band to a desired high-frequency
signal in the second intermediate-frequency-band. The same amount
of the inherent phase noise of both the light source generating the
optical carrier and the dual-mode local light source generating the
local light, which is included each in the extracted signal in the
15   first intermediate-frequency-band, is differentially removed when
the cross-multiplying is performed. With this invention, since only
two optical components which are the optical carrier and one of the
first-order optical sidebands are demodulated, there is little
degradation of high-frequency signals caused by optical-fiber
20   dispersion, compared to conventional methods.

The first embodiment of the present invention will now be
described with reference to the drawings. Figure 1 shows an
embodiment of the apparatus for transmitting high-frequency signals
in an optical communication system, according to the present
25   invention. In the drawing, reference numeral 201 denotes a
single-mode light source driving at an operating wavelength of
1550.27 nm and an output power of 5 mW. Denoted by 202 is a
high-frequency signal with the subcarrier frequency of 59.6 GHz and
the principal bandwidth of 156 MHz x 2 due to the payload data, by
30   203 is an optical intensity modulator, by 204 is an optical

transmission line that is five meters long, and by 205 is a dual-mode light source with operating wavelengths of 1549.92 nm and 1550.42 nm, each having an output power of 0.03 mW. Reference numeral 206 denotes an optical coupler, and numeral 207 denotes a photo-detector

5   with the 3-dB bandwidth of 50 GHz. Denoted by 208, 211 and 212 are electrical filters with transfer characteristics ranging from 0.05 to 50 GHz. Reference numeral 209 denotes an electrical mixer with radio-frequency (RF) and local inputs having the bandwidth of 8 to 12.4 GHz and an intermediate-frequency output having the bandwidth

10   of 0 to 3 GHz. Denoted by 210 is an electrical filter with a transfer characteristic in the 2 to 4 GHz region, by 213 is an electrical mixer having the same characteristics as the electrical mixer 209, and by 214   is   an   electrical   demodulator   in   the   second intermediate-frequency-band. Reference numeral 221 denotes the

15   first phase-noise-canceling circuit and numeral 222 denotes the second phase-noise-canceling circuit.

In Figure 1, an optical carrier f_1 emitted from the single-mode light source 201 is modulated in the optical intensity modulator 203 by the high-frequency signal 202 with the carrier frequency f_{RF} and

20   payload data. The optical intensity modulator 203 can be replaced with an amplitude modulator, a frequency modulator or a phase modulator. The high-frequency signal 202 intends to be a subcarrier signal. The modulated optical signal is transmitted to the receiving side via the optical transmission line 204. On the receiving side,

25   the dual-mode light source 205 emits local lights in a two-frequency mode, with an frequency gap f_{LO} that provides a slightly different frequency from the subcarrier frequency of the high-frequency signal 202; the frequencies being $(f_2 - f_{LO}/2)$ and $(f_2 + f_{LO}/2)$. The optical coupler 206 combines the local lights with the modulated optical

30   signal. Figure 3 illustrates the optical signal and the local lights

in front of the photo-detector 207. The photo-detector 207 carries out optical heterodyne detection, resulting in that the local lights are mixed with the modulated optical signal. Here, the mixing means a field conversion achieved by means of a substance having non-linear

5 response characteristics. As a result of the detection, the photo-detector 207 generates plural photo-detected signals in the first intermediate-frequency-band, as shown in Figure 4. The photo-detector 207 can be a photodiode or phototransistor. Using a photo-detector that is known to be a balanced receiver makes it

10 possible to reduce the effect of intensity fluctuations in the optical carrier.

The photo-detected signals in the first intermediate-frequency-band are put into the first phase-noise-canceling circuit 221, where the hatched portion is removed by the electrical filter

15 208 to thereby extract only the desired signals of frequency $(f_1 - f_2 + f_{LO}/2)$ and $(f_1 - f_2 + f_{RF} - f_{LO}/2)$, and the two extracted signals are put into the electrical mixer 209 with a square-law response. The electrically mixed and down-converted signal is then passed through the next electrical filter 210 to obtain a desired signal

20 in the second intermediate-frequency-band that has the desired frequency $(f_{RF} - f_{LO})$.

The second phase-noise-canceling circuit 222 can be replaced with the first phase-noise-canceling circuit 221, which might be preferable because of the better noise characteristics. In the

25 second phase-noise-canceling circuit 222, the photo-detected signals in the first intermediate-frequency-band shown in Figure 3 are split, with the electrical filter 211 being used to extract the first electrical component with the frequency $(f_1 - f_2 + f_{LO}/2)$ and the electrical filter 212 being used to extract the second electrical

30 component with the frequency $(f_1 - f_2 + f_{RF} - f_{LO}/2)$. These electrical

components are multiplied together with the electrical mixer 213 and extracted via the electrical filter 210 as the second intermediate-frequency-band signal with the frequency $(f_{RF} - f_{LO})$.

The phase-noise-canceling circuits shown here are examples of
5 the usable configurations. Provided they can extract the second intermediate-frequency-band signal whose phase noise originating from light sources has been completely removed, there is no limitation on methods of the bandwidth limitation of the photo-detected signals in the first intermediate-frequency-band,
10 the methods of the multiplication or the methods of the extraction of the second intermediate-frequency-band signal.

The second intermediate-frequency-band signal with the frequency of $(f_1 - f_2 + f_{RF} - f_{LO}/2)$ which is extracted by the electrical filters 221 and 222 is demodulated with the electrical demodulator
15 214 working in the second intermediate-frequency-band, by means of the well-known demodulating techniques.

There are a number of methods that can be used to produce the first optical local component from a local light source and the second optical local component from the local light source having a
20 predetermined frequency differential from the first optical local component. These can be categorized as; (a) a method of extracting two continuous waves from the spectrum from a pulsed light source, (b) a method of extracting two continuous waves from the spectrum from a pulsed light source that uses an optical injection-locking
25 technique, (c) a method of utilizing a light source that emits two adjacent lightwaves, and (d) a method of modulating light from a single-mode light source and selectively generating two lightwaves. Especially, methods that can be used include (1) using an optical filter to extract two desired lightwaves from a mode-locked laser
30 diode; (2) using a dual-mode laser diode; (3) using an optical filter

to extract two desired lightwaves from a pulsed optical-fiber laser; (4) generating two lightwaves by optical injection locking of a laser; (5) generating two desired lightwaves by four-wave-mixing in an optical non-linear device; (6) selecting two optical sideband

5 components by sinusoidal modulation of an optical carrier from a single-mode laser; and (7) generating two desired lightwaves by resolving degeneration caused by Zeeman division.

From the above explanation, the modulation scheme of high-frequency signals can be of analog or digital. There is no

10 particular limitation on modulation methods, multiplexing methods or access methods. However, the electrical demodulator 214 in the second intermediate-frequency-band should be a demodulator to cope with the modulation format of the original high-frequency signal. Considering such analog modulation systems that an optical carrier

15 is modulated by a high-frequency signal, either linear or non-linear modulation may be employed. When frequency modulation is used, the phase-noise-canceling circuit can be provided with a frequency discriminator, as in the case of phase modulation.

Figure 5 shows the measured optical spectrum in the case of

20 the above configuration. Here, the local light is obtained by suppressed-carrier double-sideband modulation using a Mach-Zehnder type intensity modulator. In this example, because the carrier suppression was insufficient, the undesired optical carrier component at frequency f_2 remained.

25   Figure 6 shows the measured spectrum of photo-detected signals in the first intermediate-frequency-band in the above configuration. The spectrum broadening included in each photo-detected signals is caused by phase noise of light sources. The undesired optical carrier component in the local light produces an undesired electrical

30 component with the frequency of $(f_2 - f_1)$ after photo-detection.

However, since the electrical filters 208, 211, and 212 can easily filter out the undesired component, the undesired component will not affect the following electrical processing. Figure 7 shows the measured spectrum of the second intermediate-frequency-band signal,

5 which is the output of the electrical mixer 209 in the above configuration. The multiplication operation differentially removes the phase noise originating from light sources, leaving just the second intermediate-frequency-band signal purely with the desired frequency ($f_{HF} - f_{LO}$). Measurements show that the line-width

10 of the second intermediate-frequency-band signal was less than 30 Hz, and single-sideband phase noise was -73 dB/Hz at 10 kHz apart from the carrier. These good results show that the optical heterodyne detection in this invention is not substantially affected by any phase noise of light sources.

15   Figure 8 shows the measured bit error rate for transmission of a millimeter-wave-band, high-frequency signal with the differential-phase-shift-keying-format data of 155.52 Mb/s and the carrier frequency of 59.6 GHz. The bit error rate is shown as a function of the optical power put into the photo-detector. From the

20 figure, it can be seen that when there is an attenuation of 2 dB, that is, when the transmission is along a 10-kilometer-long optical fiber with the transmission loss of 0.2 dB/km, a bit error rate of less than 10^{-9} can be achieved.

    Figure 9 illustrates the second embodiment of the present

25 invention. In this configuration, an optical signal received at the optical coupler 206 and dual-mode local light from the dual-mode local light source 205 are combined. Then, an optical filter 215 is used to select the first group of optical components comprising an optical sideband component included in the optical signal and the

30 first local light component, and to select the second group of optical

components comprising an optical carrier component included in the optical signal and the second local light component. By individually mixing optical components each in the group with the photo-detector 207, photo-detected signals in the first intermediate-frequency-band are generated. By passing the photo-detected signals through electrical filters 211 and 212, the desired electrical component at $(f_1 - f_2 + f_{RF} - f_{LO}/2)$ and $(f_1 - f_2 + f_{LO}/2)$ are respectively filtered out. After processing the electrical component at $(f_1 - f_2 + f_{RF} - f_{LO}/2)$ and $(f_1 - f_2 + f_{LO}/2)$ with the multiplier 213 and passing the result through the electrical filter 210, just a desired signal in the second intermediate-frequency-band at the frequency of $(f_{RF} - f_{LO})$ is obtained. The filter 215 can be a Fabry-Perot type filter, an arrayed waveguide grating, and so on.

Figure 10 illustrates the third embodiment of the present invention. In this arrangement, the received optical signal is demodulated by being mixed directly with the local light, without a step of the electrical processing in the second intermediate-frequency-band. In the configuration shown in Figure 10, the optical signal received at the optical coupler 206 and the dual-mode local light from a local light source 220 that is functionally equivalent to a dual-mode light source are combined and passed through an optical splitter 216. A fraction of the optical signal is used to extract a high-frequency signal with the frequency of f_{RF} from the photo-detector 207, and a subcarrier regenerator 219 is used to extract the subcarrier frequency f_{RF} thereof, and the output is made to coincide with the frequency gap between the local lights from the local light source 220. This coincidence is accomplished by the well-known phase-locking method. Providing the optical local source 220 with the ability to make the signals coincide with each other enables a phase-locked loop to be formed by the optical local

source 220, optical coupler 206, optical splitter 216, optical detector 207 and subcarrier regenerator 219. Therefore, when the signals coincide, the information on the high-frequency signal 202 and f_{RF} can be directly demodulated by using another electrical filter

5 217 to extract the signals in the first intermediate-frequency-band at around $(f_1 - f_2 + f_{RF}/2)$ from the other photo-detector 207 and multiplying the signals themselves in the electrical mixer 209 with the square-law response. The frequency- and phase-locking methods in the above phase-locking loop at f_{RF} can be performed by using the

10 other methods already known, and are not limited to the above method.

In the invention according to the first and fifth aspects, in coherent optical communications, if optical heterodyne detection using a dual-mode local light is adopted, phase noise from light sources does not affect the demodulation. Cost reduction is also

15 possible because of the cost-effective electrical circuit in the receiver working at lower frequency. In accordance with the second and sixth aspects, a high-frequency signal can be transmitted and demodulated even without optical amplifiers, by getting the gain of the optical heterodyne receiver. It also makes it possible to

20 prevent the demodulated signal being affected by phase noise of light sources. Moreover, it eliminates the need to use additional optical filters and optical-fiber dispersion compensators highly depending not only on the optical carrier wavelength but also on the distance traveling along the optical transmission line. The result is greater

25 flexibility with respect to configuring an optical communication system.

The third and seventh aspects of the invention also enable transmission and demodulation of a high-frequency signal, by utilizing the gain of the optical heterodyne receiver, without

30 optical amplifiers. And, the demodulated signal is not affected by

phase noise of light sources. Since the received signal is directly demodulated, the configuration can be simplified.

In the case of the fourth and eighth aspects, the desired signal frequency is selected at the post photo-detection stage, making it

5 possible to simplify the following electrical processor. The ninth aspect eliminates an extraneous source originating from background noise, so the apparatus is simplified, since it is only necessary to handle light of a single frequency for the first carrier. In the case of the tenth aspect a photo-detector is used to mix the light,

10 resulting in more efficient conversion than that achieved using an optical non-linear device.

In accordance with the eleventh aspect, the photo-detector that mixes the lights is a balanced receiver, and it reduces the effect of intensity fluctuations on the demodulated signal.

15 In the twelfth aspect, two continuous waves are obtained from optical spectrum emitted from a pulsed light source, or from a pulsed light source with optical injection locking, or by utilizing a light source that emits two adjacent lightwaves, or by selectively producing two lightwaves by modulating light from a single-mode light

20 source. This facilitates the construction of an optical heterodyne detection using a dual-mode local light source.